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DUST TRANSPORT - WIND BLOWN AND MECHANICAL RESUSPENSION
JULY 1983 TO DECEMBER 1984

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ABSTRACT

This study defines the processes that resuspend plutonium (Pu) particles from Pu-contaminated soil at Rocky Flats. Such knowledge can predict the transport of Pu particles from the site and the population dose. A vertical dust flux tower profiled the plume of Pu particles from the site. The data show a 70% reduction between 1 and 10 m in the concentration of coarse and inhalable Pu particles. The respirable particle concentration remained steady at both heights, slightly above background levels. High winds visually resuspend large amounts of dust for short periods, but we suspected that present sampling devices do not function properly above 50 km/hr. During a windstorm reaching 80 km/hr, the size-selective sampler used seriously underestimated the dust(Pu) concentration. Wind tunnel studies measured resuspension versus wind speed from our prairie grass covered, arid soil. We failed to find a good correlation between resuspension and wind speed. This led to a search for alternative mechanisms of resuspension besides wind erosion. Resuspension of dust(Pu) from grass proved to be important, as well as resuspension from rain splash.

INTRODUCTION

The primary objective of this project is to quantify the erosion process by which soil containing plutonium (Pu) is resuspended from two Rocky Flats Plant (RFP) sites known as the pad field and east field (see Figure 1). The results of this research will be used to model local Pu movement and to estimate population dose values.

Vertical dust and Pu flux in the east field were investigated, as was the relationship between the rate of Pu resuspension and wind speed. Alternative mechanisms for Pu resuspension from soil were studied. Size-selective inlets (SSIs) for high volume samplers were evaluated for use in high winds.

VERTICAL DUST AND PU FLUX IN THE EAST FIELD

Methods

A vertical dust flux sampling scaffold was placed about 100 m SE of the East Gate (see Figure 2). Three high volume air samplers (hivols), with SSIs that have a cutoff at 15 μm Aerodynamic Equivalent Diameter (AED), were used to sample the airborne dust. The SSI had to be disassembled to recover the dust (>15 μm), which is not done by the ordinary user. The internal surfaces of the SSI were oil coated to prevent bounce-off. Research at Rocky Flats has shown that this is necessary in arid climates.[1] The hivols are located 1, 3, and 10 m above ground level, as seen in Figure 2. The 1- and 10-m samplers were placed in operation during November 1982. The 3-m sampler was added in January 1984. These samplers were used to determine the vertical concentration profile of Pu-contaminated dust particles that reached the sampler after resuspension from the pad field and east field. The vertical profile helps to define how far Pu-carrying dust can be airborne, since the dust particles must rise a minimum distance above ground before the wind can carry them any significant distance.

Results and Discussion

Table 1 gives the data obtained from more than 2 years of sampling, November 1982 through December 1984. The sampling interval was two months. The cutoff for inhalable particles was 15 μm, as specified by the EPA when the project was started.[2] Table 2 summarizes the concentration data for the airborne dust and its Pu-239 content. The average values report the scatter in the point values. Dust concentration generally decreases with height, except for the respirable dust, which consists of particles that do not settle appreciably. The

TABLE 1. Dust and Pu-239 Concentration From Vertical Dust Flux Tower

Dust Concentration
($\mu g/m^3$)

Sample Period	1 m				3 m				10 m			
	Resp.[a]	Inh.	Coarse	Total	Resp.	Inh.	Coarse	Total	Resp.	Inh.	Coarse	Total
Nov-Dec '82	8.1	7.3	20	35	NDC[b]	NDC	NDC	NDC	6.8	3.8	11	22
Jan-Feb '83	8.9	7.1	36	52	NDC	NDC	NDC	NDC	7.9	5.4	19	32
Mar-Apr	11.0	9.6	22	43	NDC	NDC	NDC	NDC	10.0	6.1	14	30
May-June	6.4	8.8	30	45	NDC	NDC	NDC	NDC	6.4	8.0	18	32
July-Aug	8.0	10.0	27	45	NDC	NDC	NDC	NDC	9.3	9.0	28	46
Sept-Oct	7.4	14.0	24	45	NDC	NDC	NDC	NDC	8.4	12.0	23	43
Nov-Dec	9.3	7.0	21	37	NDC	NDC	NDC	NDC	7.3	4.5	10	22
Jan-Feb '84	8.7	11.0	47	67	8.3	10.0	23	41	8.0	7.7	26	42
Mar-Apr	9.0	11.0	27	47	5.7	7.6	19	23	6.3	7.1	15	28
May-June	6.9	12.0	26	45	6.9	11.0	25	43	6.4	9.7	20	36
July-Aug	8.9	15.0	24	48	7.6	12.0	20	40	7.0	10.0	18	35
Sept-Oct	7.3	13.0	21	41	10.0	12.0	21	43	8.1	9.2	14	31
Nov-Dec	6.2	11.0	45	62	6.3	9.7	54	70	5.5	7.6	36	49

Pu-239 Concentration
(aCi/m^3)

Sample Period	1 m				3 m				10 m				S7-S9 E. Gate Samplers[c]	Local Background[d]
	Resp.[a]	Inh.	Coarse	Total	Resp.	Inh.	Coarse	Total	Resp.	Inh.	Coarse	Total		
Nov-Dec '82	4.5	4.6	55	64	NDC[b]	NDC	NDC	NDC	26.0	26.0	44.0	96.0	250	2
Jan-Feb '83	11.0	8.0	190	210	NDC	NDC	NDC	NDC	7.9	3.6	40.0	51.0	260	1
Mar-Apr	5.5	8.6	45	59	NDC	NDC	NDC	NDC	28.0	9.1	10.0	47.0	200	4
May-June	5.6	29.0	51	86	NDC	NDC	NDC	NDC	8.9	4.5	28.0	41.0	650	4
July-Aug	4.9	19.0	52	76	NDC	NDC	NDC	NDC	2.4	5.8	19.0	27.0	580	4
May-June	5.6	29.0	51	86	NDC	NDC	NDC	NDC	8.9	4.5	28.0	41.0	650	4
July-Aug	4.9	19.0	52	76	NDC	NDC	NDC	NDC	2.4	5.8	19.0	27.0	580	2
Sept-Oct	1.4	19.0	27	47	NDC	NDC	NDC	NDC	0.9	7.0	49.0	57.0	340	1
Nov-Dec	0.0	0.2	31	31	NDC	NDC	NDC	NDC	0.0	0.0	4.9	4.9	130	2
Jan-Feb '84	3.1	20.0	320	340	1.7	2.7	17	21	0.0	0.0	35.0	35.0	160	2
Mar-Apr.	0.48	7.9	92	100	2.6	13.0	32	48	3.7	1.5	15.0	20.0	360	4
May-June	4.8	23.0	99	130	0.0	13.0	60	73	4.7	0.0	26.0	31.0	380	5
July-Aug	5.2	32.0	91	130	24.0	11.0	56	91	5.8	4.2	14.0	24.0	880	2
Sept-Oct	0.8	53.0	42	96	43.0	12.0	82	190	3.4	4.3	13.0	21.0	400	4
Nov-Dec	NDA[e]	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA

4% 20 76%

a. Size ranges: Respirable <3 μm
Inhalable 3-15 μm
Coarse >15 μm

b. NDC - No data at 3 meters collected until January 1984.

c. Average of samplers S7, S8, and S9 for the same sampling period as vertical flux samplers.

d. Local background is based on Surveillance Sampler 31 west of the plant.

e. Data not yet available.

TABLE 2. Summary of Dust and Pu-239 Concentration Data From Vertical Dust Flux Tower, November 1982-December 1984

Sampling Height (m)	Average Dust Concentration ($\mu g/m^3$)			
	Resp.[a]	Inh.	Coarse	Total
1	8.2 ±1.3	11 ±2.6	28 ± 8.9	47 ± 9.0
3[b]	7.5 ±1.5	10 ±1.7	27 ±13	43 ±15
10	7.5 ±1.3	7.7 ±2.3	19 ± 7.3	34 ± 8.5

Sampling Height (m)	Average Pu-239 Concentration (aCi/m^3)					
	Resp.	Inh.	Coarse	Total	East Gate S7, S8, & S9 Surveillance Samplers (Average)	Local Background
1	3.9 ± 3.1	18 ±14	91 ±85	110 ±86	380 ±220[c]	2.8 ±1.4
3[b]	14 ±19	10 ±4.4	49 ±25	75 ±45		
10	7.6 ±9.5	5.5 ±7.1	25 ±14	38 ±24		

a. Size Ranges: Respirable <3 μm
Inhalable 3-15 μm
Coarse >15 μm
b. Covers the period from January to December 1984 only.
c. Surveillance Samplers unable to fractionate dust.

same trends hold for the Pu particles,* except for the respirable Pu-239 which are near Denver background levels. Data at background level are more variable because the concentrations are near the minimum detectable limits.

Statistical analysis was conducted to confirm the above qualitative observations, **that dust and Pu concentrations decrease with height except in the respirable fractions.** The SAS statistical package** on a Digital Equipment Corporation VAX computer (VMS Operating System) was used to carry out the analysis. The results are presented in Table 3. The results show that the observed trends are all statistically significant at the levels indicated. These trends may be used to model the potential emission of Pu-239 from the site. **The Pu-239 concentrations fall off twice as fast as the dust concentrations.** It confirms previous direct measurements indicating that the **Pu-239 is attached to the larger dust particles, i.e., 70 to 80% of activity is carried by particles >15 μm (see Reference 3).** In dispersion calculations, the assumption is often made that the contaminant concentration is equally distributed throughout the dust.[4]

Futhermore, the statistics show no trends with time for the Pu concentrations, i.e., no decrease in concentration over the two years, as would be expected from rapid weathering-in effects. The statistical results also indicate that the vertical dust experiment can be terminated by the end of 1985. By then the observed trends should all be well established at a 95% or higher confidence level.

Tables 1 and 2 also refer to Pu-239 data from the S7-S9 Surveillance Samplers located near the East Gate (see Figure 1). This type of sampler collects the total Pu, i.e., no dust fractionation takes place

*When discussing Pu particles, it is understood that the Pu is attached to host particles.
**SAS Institute Inc., Box 8000, Cary, N.C. 07511.

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TABLE 3. Summary of Statistical Evaluation of Vertical Dust and Pu-239 Particle Flux Data

Are differences in concentration given in Table 2 between 1 and 10 m statistically significant?

	Dust Flux Concentration		Pu-239 Flux Concentration	
Respirable	No	(0.088)*	No	(0.17)
Inhalable	Yes	(0.001)	Yes	(0.025)
Coarse	Yes	(0.001)	Yes	(0.016)
Total	Yes	(0.001)	Yes	(0.014)

Are differences in concentration given in Table 2 between 1, 3, and 10 m statistically significant?

	Dust Flux Concentration		Pu-239 Flux Concentration	
Respirable	No	(0.39)*	No	(0.16)
Inhalable	Yes	(0.0099)	Yes	(0.019)
Coarse	Yes	(0.048)	Yes	(0.027)
Total	Yes	(0.012)	Yes	(0.019)

*Number in parentheses gives the fractional probability that the sample means do not differ significantly. For the present case, a 5% probability level was used as being significant.

but particles >20 µm are increasingly rejected by the inlet. Comparison of these data with the total Pu data from the scaffold at 1 m indicates that 100 m to the east there is one-third less Pu-239. Data from these samplers may be useful for Pu-239 transport modeling along with the scaffold data. Both sampling systems are exposed to the same Pu source. However, it must first be shown that these two sampling systems respond similarly to Pu-239 concentration changes in the >20 µm range. T-tests for the 1983-84 period showed no correlation between the samplers. The differences relate to sampling efficiency for larger (>20 µm) particles and inlet operation characteristics during high winds.[5]

Additionally, the S7, S8, S9, and S31 Surveillance Sampler data from 1976 to 1985 were statistically tested to determine if these data showed any change in Pu-239 concentration over time because of weathering-in effects.[6] A single abrupt change in concentration was noted, and was associated with the 1978 removal of some of the contaminated soil east of the asphalt pad (see Figure 1). Figure 3 illustrates these results which are statistically significant for all three samplers. Before and after this date in the summer of 1978, there were no annual trends for the Pu-239 values. If there are weathering-in effects, they must be slow at this point in time.

EVALUATION OF SIZE-SELECTIVE INLET (SSI) IN HIGH WINDS

The SSI used for the vertical flux experiment had not been previously evaluated at high wind speeds. Winds up to 140 mph are occasionally encountered at the Rocky Flats Plant (RFP), as well as sustained winds over 50 mph that last for days.[7] These episodes are responsible for much of the dust transport at RFP.[8] Wedding (1982) cites an evaluation of the SSI up to 24 km/hr with no bias in dust collection.[9] No wind tunnel facilities, like those of Wedding, are available at Rocky Flats so the evaluation at high wind speeds was based on direct field observation. Consequently, the following observations are of a qualitative nature.

To discern wind speed effects, the uniformity of the dust deposits in the SSI was observed. The SSI acts as an impactor. The construction of the impactor is shown in Figure 4. The only significant change in the dust deposits occurred during December 1984; that is, the usual uniform dust deposits changed to a very distorted pattern during December 1984. From December 21 to December 23, winds in excess of 90 mph were encountered. The daily average winds were near 30 mph according to the RFP meteorological records.

The dust images for December 1984 are shown in Figure 4. During high winds, air in excess of that aspirated by the blower was forced into the upwind side of the SSI. The inlet has an annular slit-like opening along the upper periphery that can be seen in Figure 2. The wind speed on entering the inlet was high enough so no dust settled out on the impactor inlet plate, nor entered the jets until most of the distance across the intake area. This was evidenced by the lack of extra dust visible on the upwind side of the inlet plate and on the impactor plate. On the downwind side of the inlet, the excess air was dissipated out of the sides and additional dust from the wind storm was collected. The additional dust deposits were clearly visible as dark areas on the inlet plate and on the collector plate as dark circles where it faces the nozzle. From Table 1, the most dust was collected in November-December, as would be expected because of the winds. How much the dust collection data are biased by this effect is not known. A project has been started to select a better inlet design for future studies and for a new surveillance sampler design.

RATE OF PU RESUSPENSION VERSUS WIND SPEED

A major objective of this work was to provide sufficient data on Pu transport for developing a site-specific model of population dose. The fundamental resuspension parameter is the mass of Pu released per unit time and from a unit area for different wind speeds. This parameter was studied by wind tunnel measurements. Sufficient data have been collected to consider the derivation of the relation between wind speed, soil surface condition and soil moisture. As the soil moisture for bare areas nears 30%, all resuspension ceases almost at once. Soil surface conditions are not well defined for the fields in question and this was dealt with by taking many samples. All data available have been summarized in a recent report.[3]

Wind tunnel data so far have only been collected from areas that are relatively bare or at best have sparse grass a few cm high. Such areas were considered to be the only source of airborne Pu in the original experimental plan. The truth of this assumption is discussed later. During this report period, the data were examined by statistical methods to establish numerical correlations between Pu and dust release and wind speed. Various fits were considered, including transformations. A linear and quadratic fit showed the only promise.

The quadratic model provided the best fit to the wind tunnel dust and Pu resuspension rates. These best fit curves and equations are shown in Figures 5 and 6. The r^2 values of 0.60 and 0.33 for dust and Pu release respectively indicate that the proposed numerical relationships are not very accurate. A linear fit was also tested but it gave a poorer fit, i.e., an r^2 of 0.39 and 0.20 respectively for dust and Pu. The quadratic fits are the best for the data but are more in the nature of a qualitative statement. The quadratic fit supports field observations that high winds resuspend increasing amounts of dust but these release rates are not sustained for a long period of time. The available loose surface dust is exhausted in time. The soil at RFP contains a fairly good prairie grass cover and some loose gravel. Gravel breaks the wind force right at the surface. Also, RFP soil tends to be crusty.

A previous publication reports data from wind tunnel tests carried out on the same spot of soil for 1, 15, and 45 min.[3] The data discussed above were based all on 1-minute runs. Dust release dropped off rapidly in the first few minutes and then continued at a diminished rate. Figure 7 presents both dust and Pu resuspension rates versus time of soil exposure. The Pu resuspension rate parallels the dust release. For modeling, the resuspension rate after 60 min should be used to estimate the release of dust over prolonged periods.

ALTERNATE MECHANISMS FOR PU RESUSPENSION FROM SOIL

So far, it has been assumed that Pu is directly released from soil surfaces by wind action only (saltation). This mechanism is only applicable above 35 mph winds for bare areas at RFP, based on laser light beam observation of the resuspension process.[10] Airborne dust measurements have shown that Pu is routinely released at wind speeds below the threshold value for dust resuspension by saltation. Pu is also resuspended when the ground is completely wet from rain.

During much of the year there is relatively good vegetative cover, with little exposed bare soil. Grass has been studied for its ability to collect dust. However, its ability to release dust has not been investigated until our recent tests. Dust was released during a wind tunnel experiment at 22 mph, at a low rate of 0.13 g/m^2-min, from areas covered with light grass and soil covered with litter.[3] The corresponding Pu resuspension value is now available--0.12 nCi/m^2-min Pu-239 were released based on 15 one-minute samples. Previous findings at higher wind speeds demonstrated higher plutonium releases.[8] Since significant amounts of ... were released by 22-mph winds, the details of ... process for resuspension of Pu from grass and ... merited study. Evidently significant amounts ... are on the grass blades, which had not been ...dered so far. Vegetative litter would still carry Pu. Litter, because of its fluffy nature, is easily ...pended.

...pension of Pu From Grass

...irst step in this study was to collect informa... on the amount of Pu on grass. Past work on Pu take-up in December 1980 included ...tion of 200 g of grass clippings at Sites 2-8 in ...d field (see Figure 1). The average soil activity ...ampling area was 550 pCi/g Pu-239. Dust in ...ount of 1.6 g was washed from the grass with chlorothene. The dust contained 110 ... Pu-239. The source of the dust could be ...blown soil particles. However, studies at Los ...os suggested rain splash as a primary ...nism for surficial dust contamination of the ... 30 cm of plants.[11]

A systematic study of Pu activity carried by grass was started in July 1983. At that time it was known that Pu, if present, resides principally on the surface of plants, i.e., internal plant take-up of Pu is small.[12] Twenty-nine grass samples from Sites 12, 13, and 17 near the East Gate (see Figure 1) were analyzed directly for Pu instead of washing off the dust.

The data from the 29 samples are summarized in Tables 4 and 5. The first two sets of samples included dried-out grass litter at the base of the grass. This litter could receive soil activity by direct contact with the soil or from standing water. The data are reported in terms of Pu per gram of ashed grass. Pu becomes airborne from the grass blades as loose dust and with pieces of decayed grass (litter). Thus, the activity of the ashed grass is indicative of potential airborne activity. The counting error at the 95% confidence level varied from 1 to 7%. Duplicate samples were within ±20%, with a few exceptions.

The data show that grass plus litter has seven times the activity of grass only. However, grass and litter still have much less (1/20th) activity than bulk soil (see Table 4, first column). Table 5 gives the data for a 10-m traverse across the east field to assess activity on grass over a wider area. As before, the activity varied widely but it averaged out to the same value as the above samples. The variability is related to the type of grass involved; also, weeds were often encountered. This led to wide variations in vegetation surface areas. Scanning electron microscopy is in progress to study the microscopic surface structure of different grass blades.

Information was obtained concerning the Pu activity distribution on grass blades versus height (Table 6) at Sites 12 and 17. One important result was that, above the litter level, grass blades carried a fairly constant amount of Pu, i.e., the activity varied no more than a factor of 2. This study shows that Pu is available for resuspension from grass up to the top of the blades. Single grass blades are being studied for dust release with an optical particle counter.

The activity of ashed grass without litter was compared to that of the airborne dust at the scaffold.

TABLE 4. Plutonium Concentration on Grass Collected 7/26/83 From a 4 m² Area Near East Gate

Site	Soil Activity	Weight of Air-Dried Grass Sample Aliquot (g)	Ash Content of Grass (%)	Pu-239 Activity (pCi/g Ash)	Comments
Site 12	2,200 pCi/g	10	4.9	31	Cut to 0.5 cm off the ground,
	Pu-239 in	10	5.8	180	*includes* litter.
	Soil	10	4.6	15	
		10	6.0	110	
		10	6.1	57	
			5.5 ±0.68	78 ±67	
Site 13	2,600 pCi/g	10	8.8	210	Cut to 0.5 cm off the ground,
	Pu-239 in	10	6.2	290	*includes* litter.
	Soil	10	6.7	110	
		10	5.7	120	
		10	5.1	1	
			6.5 ±1.4	150 ±110	
Site 13	2,600 pCi/g	5	5.8	0.8	Cut to 2.5 cm off the ground,
	Pu-239 in	5	4.2	45	*no* litter.
	Soil	10	4.5	9.1	
		10	4.7	34	
			4.8 ±0.70	22 ±21	
Site 17	3,700 pCi/g	10	4.3	11	Cut to 2.5 cm off the ground,
	Pu-239 in	5	6.6	21	*no* litter.
	Soil	5	8.4	5.4	
		5	4.6	60	
		5	5.8	35	
			5.9 ±1.7	25 ±22	

TABLE 5. Plutonium Concentration on Grass* Collected 7/28/83 Along a Traverse From Site 17 Near East Gate

Sample Distance From Site 17 to East (m)	Weight of Air-Dried Grass Sample Aliquot (g)	Ash Content of Grass (%)	Pu-239 Activity (pCi/g Ash)
1	5	5.0	14
2	5	6.2	59
3	5	5.0	0.9
4	10	15	0.3
5	5	5.4	0.8
6	10	3.3	48
7	5	4.0	1.1
8	5	3.8	62
9	5	5.2	37
10	10	4.1	1.1
		5.7 ±3.4	22 ±26

*Cut above ground litter.

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TABLE 6. Plutonium Concentration Versus Height on Grass Blades Collected 8/6/84 From 3-m² Sampling Area Near East Gate

Site	Soil Activity	Height of Cut (cm)	3-m² Weight of Air-Dried Grass Sample (g)	Ash Content of Grass (%)	Pu-239 Activity (pCi/g Ash)
Site 12	2,200 pCi/g Pu-239 in Soil	0-5.1*	360	17	510
		5.1-15	140	6.1	74
		>15	52	4.8	67
Site 17	3,700 pCi/g Pu-239 in Soil	0-5.1*	310	8.4	640
		5.1-15	170	6.3	36
		>15	41	4.1	66

*Includes litter and some soil. Grass was cut right to ground.

TABLE 7. Wind Tunnel Measurements to Determine Resuspension of Pu-239 From Soil Only and From Grass Only

Site, Date	Site Condition	Activity Concentration in Resuspended Dust: Am-241 by γ-spec* (pCi/g)	Pu-239 by α-spec (pCi/g)	Th-234 by γ-spec* (pCi/g)	Activity Ratios: Pu-239: Am-241 Resuspended Dust (pCi/g)	Pu-239 in Resuspended Dust: Pu-239 in Soil (pCi/g)	Resuspension Rate at 80 mph: Pu-239 (nCi/m²-min)	Dust (g/m²-min)
Site 12 8/6/84	Grass cut to 0.5 cm, 2,200 pCi/g Pu-239 in soil	220 ±10	1700 ±200	7.7 ±4.7	7.9	0.77	1.3	0.75
Site 17 8/6/84	Grass cut to 0.5 cm, 3,700 pCi/g Pu-239 in soil	380 ±7	1900 ±200	5.2 ±3.6	4.9	0.51	3.4	1.8
Site 13 8/8/84	Grass *not* cut, but soil wet 2,600 pCi/g Pu-239 in soil	130 ±15	1200 ±100	<5.0	9.0	0.46	0.038	0.032

*Average of 3 measurements. Shook vials between each count to check on presence of hot particles.

Over two years at 1 m, the dust activity averaged 2.3 pCi/g Pu-239. The ashed grass residue holds 23 pCi/g Pu-239 in ash. The ash activity is high enough to account for at least part of the activity seen at the scaffold. **This assumes the ash data are indicative of the activity of decayed grass particles and dust resuspended from grass blades.** Therefore, Pu released from grass alone must be considered a source of airborne Pu particles at RFP. Litter particles are not as accessible to light wind action because the litter particles are on the ground beneath the grass.

A special wind tunnel test was conducted to determine if the low speed Pu resuspension was a wind tunnel artifact. **It was possible that loose plant debris, caught at the base of the grass blades, was pulled up because of the higher velocity near the ground in the wind tunnel, compared to the real atmosphere.** Therefore, ground in the area to be tested with the wind tunnel was soaked carefully with water without wetting the grass, so only dust could be released from grass blades. The results are shown in Table 7. Also, two similar runs of 20 one-minute samples each were made in two areas where the grass had just been clipped to 0.5 cm, leaving the litter exposed. These two runs gave typical dust resuspension rates for grass litter. As seen from Table 7, the dust and Pu release from grass blades only was about 1 to 4% of that from a litter surface. Still, this confirms that Pu is resuspended from grass (weed) blades alone. At low wind speeds (<20 mph), grass blades appear to be the only source of Pu. This will be discussed below. Keep in mind that mechanical resuspension is not a factor because the Pu-contaminated soil areas are restricted from traffic.

The above data for Pu suspension from grass only were collected at a 10-m equivalent velocity of 80 mph. This raises the question of how Pu would be emitted at low wind speeds. We can estimate the release of Pu at 20 mph, for example, from the graph in Figure 6. It indicates that Pu emission from grass would be reduced by a factor of 40 as the wind speed decreases from 80 to 20 mph, i.e., resuspension decreases from 0.04 to about 0.001 nCi/m^2-min. This compares to a release of 0.1 nCi/m^2-min at 22 mph given earlier in this section for an area covered with light grass and soil with a litter layer. This is higher by a factor of 100 than the release from grass alone and it may seem that dust release from grass is not important.

However, as stated earlier, we limited the wind tunnel studies so far to bare soil or areas with sparse grass less than a few centimeters high. The original premise was that Pu suspension could only take place by saltation, a process where particles at least 1-mm in size are rolled along the soil surface by winds over 30 mph. These particles impact the soil and knock loose fine dust, i.e., resuspend it. In our case, saltation areas are of limited extent and vary with season, annual rainfall, etc. A rough estimate is that 95% of the fields are covered with a good stand of grass must be considered, along with resuspension of litter, even at low velocities.

Resuspension of Pu by Rain Splash

Rain splash may resuspend soil particles and transfer them to plant surfaces. High speed photography has shown that small droplets are formed when drops impact on a surface.[13] Some of the droplets may carry surface particulates and, upon evaporation, these particles are free to remain airborne for some distance. In still air, droplets are projected over horizontal distances up to one meter and up to 5,000 droplets/splash have been recorded.[13] The droplets ranged from 5 μm to 2.4 mm, with a median diameter of 70 μm. Gregory has proved that this process is responsible for spreading plant diseases over large areas.

This mechanism explains a previously unexplained observation shown in Figure 8. During a one-year sampling project in the pad field, weekly dust samples were collected with an ultravol air sampler (300 cfm) and analyzed for Pu. There were week-long periods in the spring of 1981 when the field was continuously wet due to rain but there was no significant reduction in Pu concentrations. The only time when no Pu above fallout levels was reported was during a period of snow cover in the first part of March 1981. There was a thirty-fold reduction in Pu concentration during this period.

A laboratory and field study project on rain splash will be initiated in the summer of 1985.

CONCLUSIONS

It is now evident that at Rocky Flats there are a number of resuspension processes for Pu in soil, such as wind erosion of bare soil, resuspension from grass, resuspension of litter, and resuspension by rain splash. Some of these processes have not been investigated before. Soil resuspension studies are generally limited to bare ground and most work has been done for plowed fields. These different resuspension phenomena must be incorporated into a unified model.

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ILLUSTRATIONS
(Figures 1 Through 8)

FIGURE 1. Aerial Photograph of Dust Transport Study Area

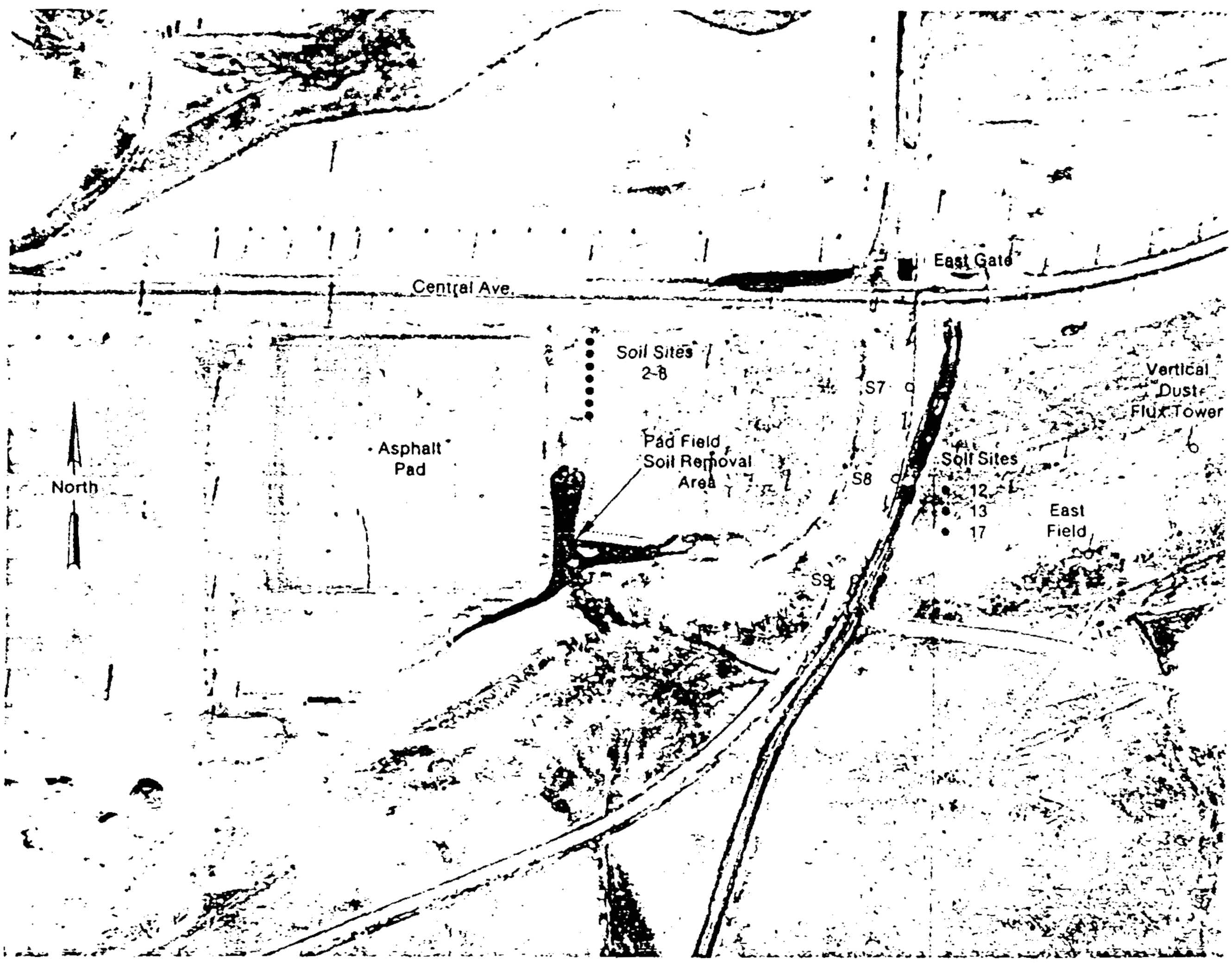

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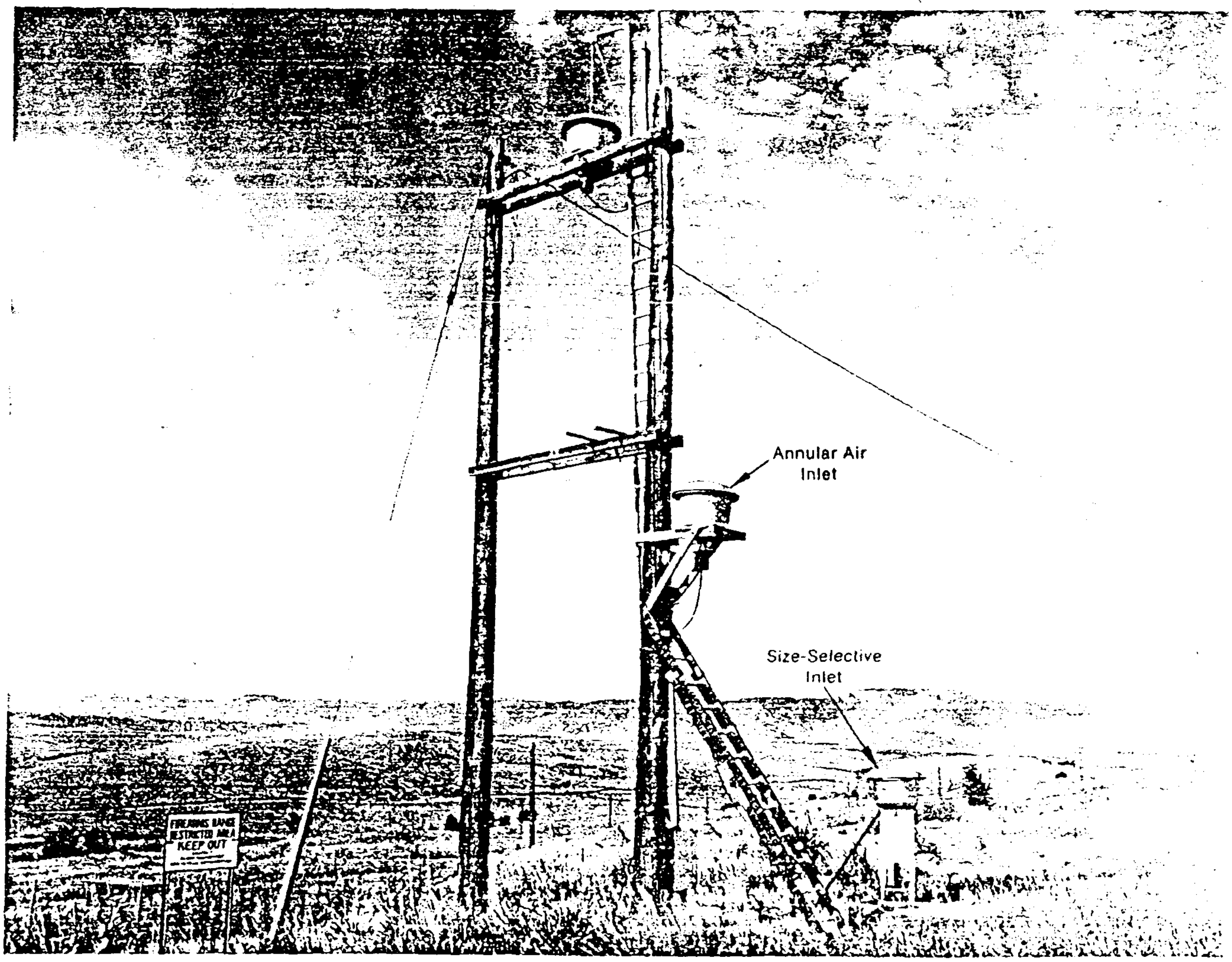
FIGURE 2. Vertical Dust Flux Tower



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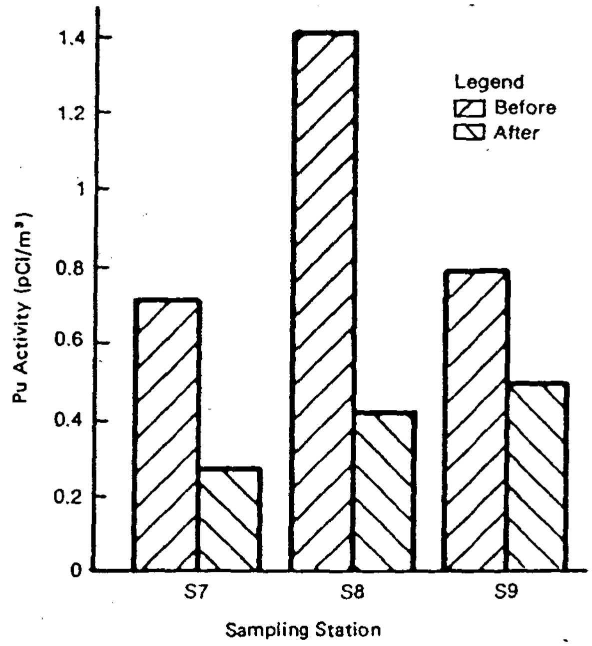
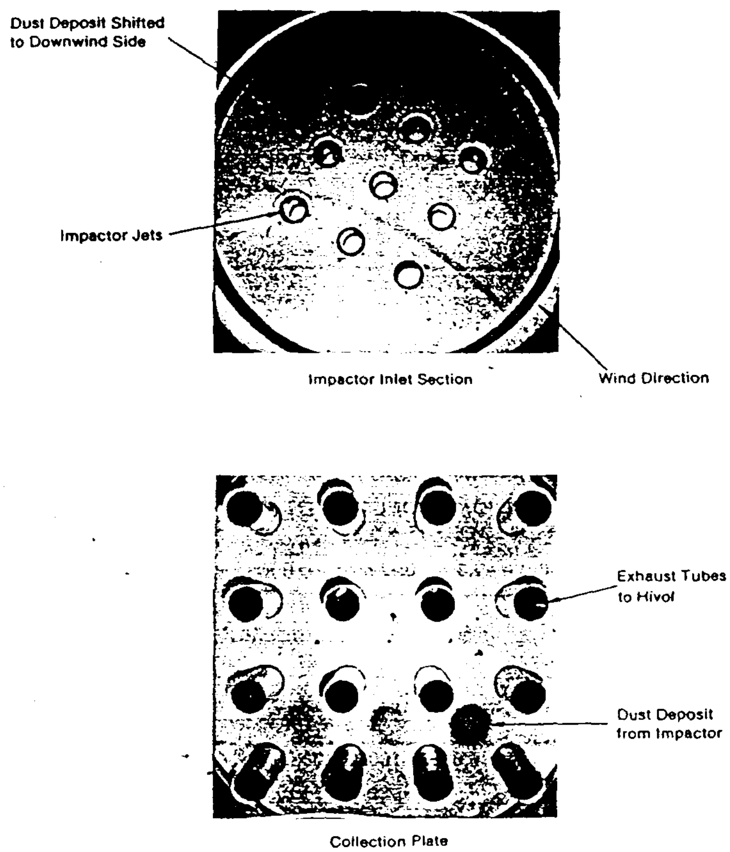


FIGURE 3. Amount of Pu Before and After 1978 Cleanup

FIGURE 4. Size-Selective Inlet - Internal Appearance After Windstorm Period in December 1984. All surfaces were oiled.



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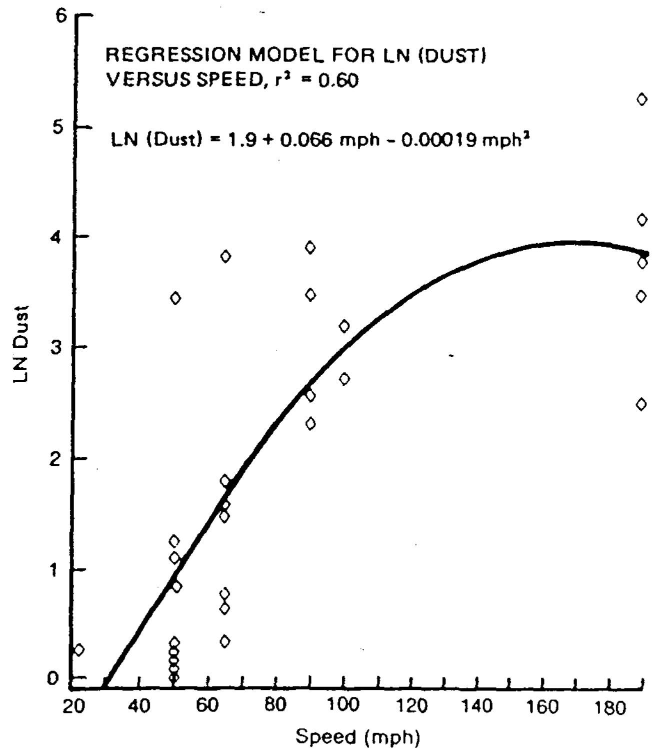

FIGURE 5. Quadratic Curve Fit to Dust Resuspension Data

FIGURE 6. Quadratic Curve Fit to Pu Resuspension Data

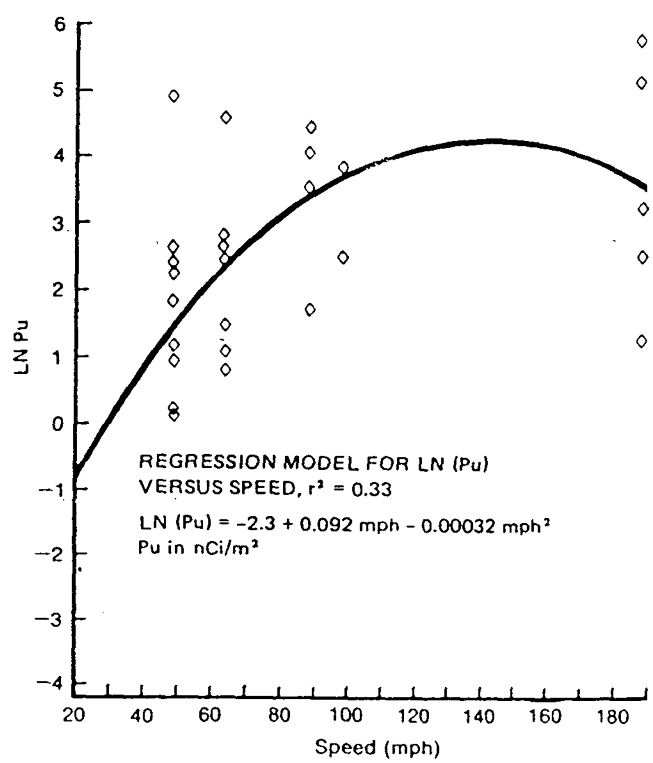

FIGURE 7. Rate of Dust Resuspension at a Fixed Location Versus Time of Exposure at 90 mph. Soil Activity 940 pCi/g in Test Area.

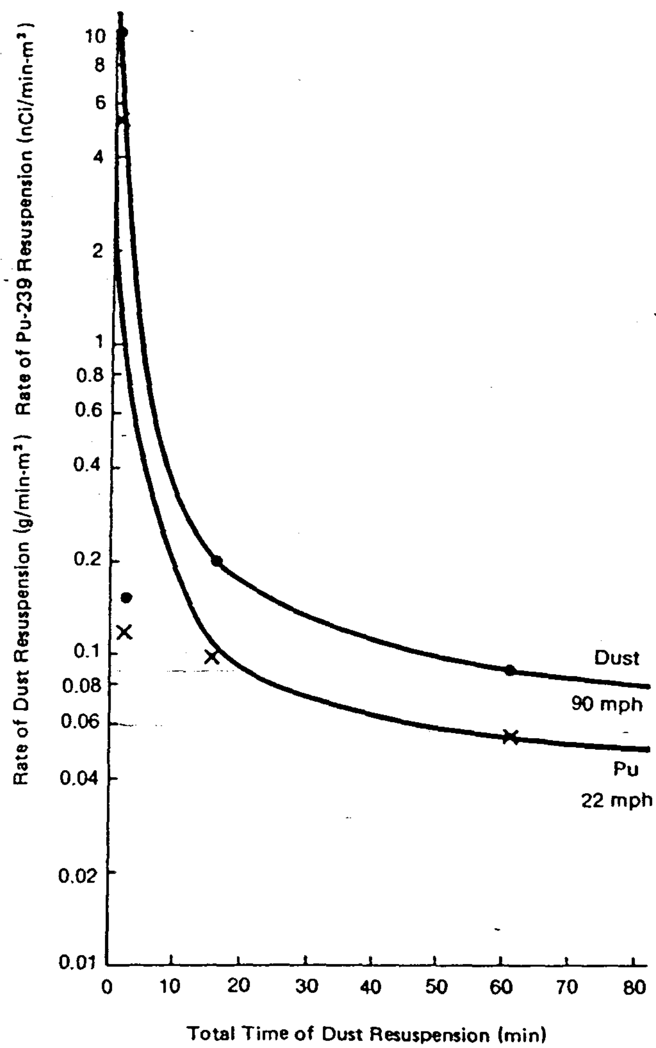

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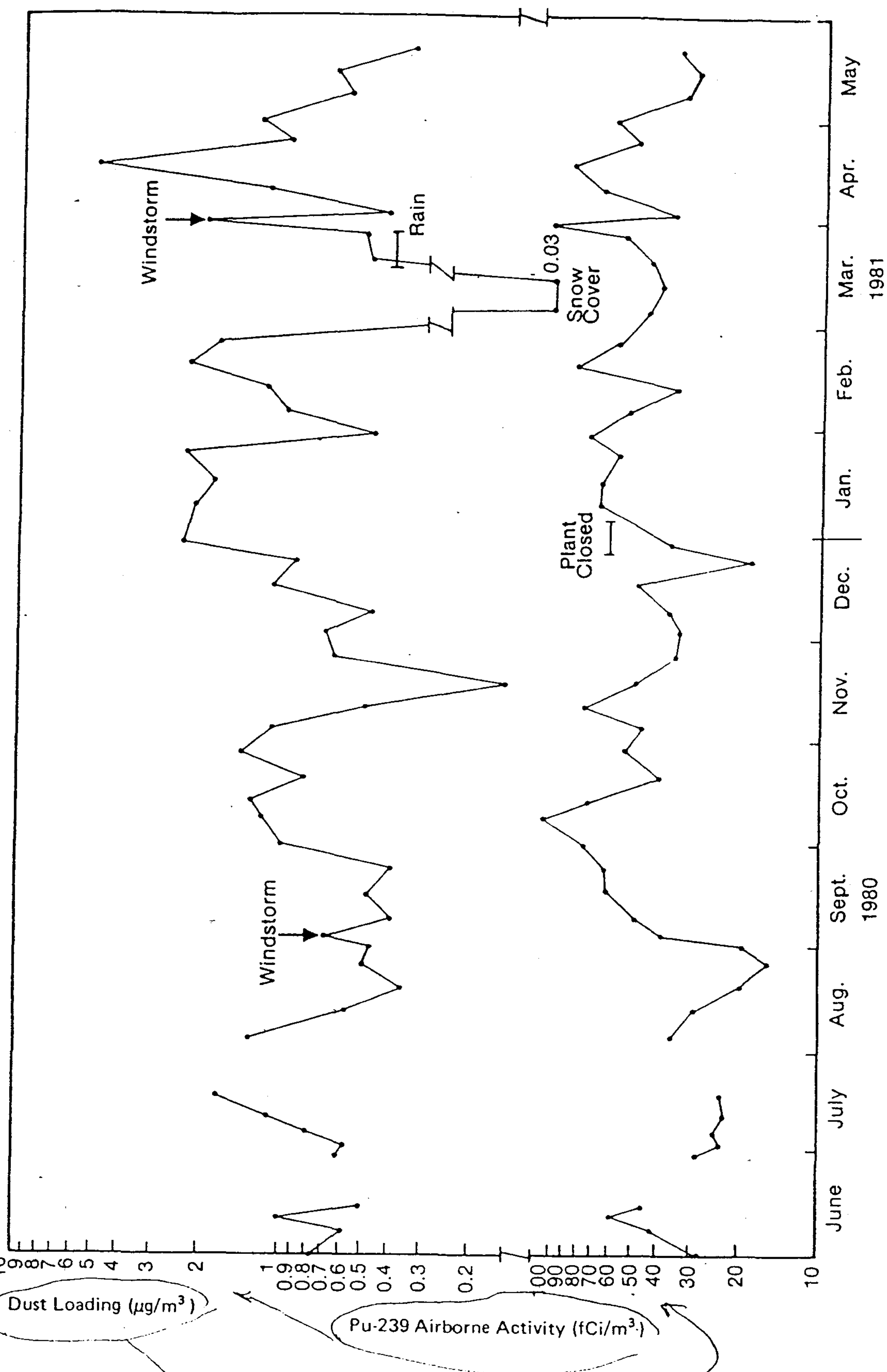
FIGURE 8. Summary of Radioactivity Detected in Center of Pad Field



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